DOCUMENT RESUME

ED 408 196 SE 060 300

AUTHOR Czarnik, John C., Jr.; Hickey, Daniel T.
TITLE Problem Generation in the Mission to Mars Curriculum.
PUB DATE 25 Apr 97
NOTE 25p.; Paper presented at the Annual Meeting of the American Educational Research Association (Chicago, IL, March 24-28, 1997).
PUB TYPE Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Astronomy; Educational Strategies; Elementary Secondary Education; *Problem Solving; Science Activities; Space Exploration; *Space Sciences; Teaching Methods
IDENTIFIERS Mars (Planet)

ABSTRACT

This paper will explore a problem finding task the authors developed as one component of the Mission to Mars curriculum, an inquiry-based science unit developed by Petrosino & The Cognition and Technology Group at Vanderbilt (CTGV). The paper also attempts to address evolving conceptions of the problem generation task, primarily from that of an independent variable to that of a dependent variable. The first section provides a brief overview of the Mission To Mars curriculum, specifically focusing on problem-finding activities that were used to structure classroom discussions and research. The second section presents attempts to understand the initial and post-instruction problem generation activity of students participating in the Mission To Mars curriculum, beginning with a theoretical discussion on the nature of context, noticing, and expertise, and the roles that expertise might play in problem-finding activity. Participants in the study were 17 ethnically diverse students in a sixth-grade class that reflected a typical inner-city classroom in public schools in Nashville, Tennessee. Findings indicate that initially students asked very general questions which were often tangential to the established problem domain. Those questions posed initially that were well specified were often focused upon trivial issues. Relative to initial attempts, problems generated at post-instruction were more appropriate with regard to the planning task and tended to deal with specific relevant issues. It is concluded that in addition to motivating students and developing a sense of ownership of issues in a domain, problem generation activity sensitizes students to the complexities of the tasks to be completed. Contains 23 references. (JRH)

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Running Head: PROBLEM GENERATION IN MISSION TO MARS

Problem Generation in the Mission to Mars Curriculum

John C. Czarnik, Jr.
Learning Technology Center,
Vanderbilt University

Daniel T. Hickey
Educational Testing Service,
Princeton, New Jersey

Paper presented at the 1997 American Educational Research Association Annual Meeting, in Symposium session 16.41, The reflexive nature of practice and research within learning environments.

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Address correspondence to:

John C. Czarnik, Jr.
Box 45 GPC
Learning Technology Center of Vanderbilt University
Nashville, TN 37203
Phone: (615) 322-8070
Fax: (615) 343-7556
Email: John.C.Czarnik@vanderbilt.edu

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Problem Generation in the Mission to Mars Curriculum

> The formulation of a problem is often more essential than its solution, which may be merely a meter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old questions from a new angle, requires creative imagination and marks real advance in science (Einstein & Infeld, 1938, p. 92, cited in Getzels, 1979).

The process of finding problems, as opposed to solving them, has long been advanced as a central element of superior performance and creative genius in the arts and sciences. Clearly, problem finding represents an act which is distinct from solving problems which have already been identified.

According to Getzels (1979),

> the portion of human activity that is held in highest esteem as uniquely human- activity that can be described only as pure science, fine art, basic research, systematic philosophy- is devoted as much to finding or creating problems as to solving problems (p. 169).

Despite the value of problem finding as stated by Getzels and Einstein & Infeld (1938), this activity is rarely to be found in our classrooms. This paper will explore a problem finding task that we have developed (Hickey et. al., 1995), as one component of the Mission to Mars curriculum, an inquiry based science unit developed by Petrosino & CTGV (1995).

Our paper will attempt to address our evolving conceptions of the problem generation task, primarily from that of an <u>independent</u> variable to that of a <u>dependent</u> variable. To accomplish this goal, will divide our paper into two sections. The first section of our paper will provide a brief overview of the Mission to Mars curriculum, specifically focusing on our problem finding activities (The Mars Mission Challenge) that we used to structure classroom discussions and research (i.e. problem finding as an <u>independent</u> variable). We will also discuss our initial attempts at making sense of the problems that students generated in these activities, as reported by Hickey et. al. (1995). The second section will present our most recent attempts at understanding initial and post-instruction problem generation activity of students participating in the Mission to

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Mars curriculum (I.e. problem generation as a dependent variable), beginning with a theoretical discussion on the nature of context, noticing, and expertise, and the roles that expertise may play in problem finding activity. Predictions derived from this discussion will be tested in an initial investigation of differences between pre and post-instruction problem generation activity in the Mission to Mars curriculum.

The Mission to Mars Curriculum

The Mission to Mars curriculum is designed to lead students to generate problems about the scientific challenge of planning a Mars mission, and to support student inquiry into solving these problems. Planning a trip to Mars is an excellent problem space because it lends itself to subproblems from every academic domain, thus making it inherently cross-curriculum. The Mission to Mars program consists of five steps, beginning with a starter unit and pre-assessment, followed by the Mars Mission Challenge video and problem generation activities, leading to research in cooperative teams, jigsaw group formation, and culminating in a feasibility study by the jigsaw groups. The Mars Mission curriculum takes about 2 - 3 months to complete. Figure 1 graphically depicts the instructional sequence.

Insert Figure 1 about here

Within each of the phases presented in Figure 1, a variety of instructional activities have been developed targeted at specific research activity or conceptual reorganizations. Most of these activities are far beyond the scope of this paper, and we refer readers interested in the project to Petrosino (1995) for the specifics of the curriculum content, and to Sherwood, Petrosino, Lin, Lamon, & The Cognition and Technology Group at Vanderbilt (1995), and Petrosino & Moore (1996) for principles underlying its design. However, as problem generation is the focus of the present paper, we will give some attention to typical classroom activities during this phase of the curriculum.

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Problem Generation Lessons

After participating the starter unit and pre-assessment, students begin the problem generation phase of the Mission to Mars curriculum. To facilitate problem generation, the Learning Technology Center at Vanderbilt University has developed a seven-minute video using existing NASA footage. The Mars Mission Challenge video visually suggests the wide variety of factors involved in planning and carrying out a human mission to the planet Mars. The video narration explicitly challenges students to pose problems within the domain of planning a mission, although it does not limit the students to generating specific problems. After showing the Challenge video, students are asked to generate an exhaustive list of potential problems to research in order to actually plan and complete a manned mission to the planet Mars.

Once individual students are done generating problems, the class, with guidance from the teacher, sorts the questions into categories, one for each research group. These categories closely mirror the various disciplines that students in middle school encounter. Typically, groups formed are: Medical (human factors), Supply (Equipment, Food), Engineering (Navigation /Propulsion), Environmental Preservation (Spacecraft environment), Spacecraft Design, and Surface Exploration. These groups cover major areas of concern for space travel.

After the formation of research groups, students are handed the list of questions the class generated for their category, to help guide their research activity. For the next few months, the students continue through the various phases, as outlined by figure 1.

The problem generation lessons were incorportated in the Mission to Mars curriculum for several reasons. We believe the problem generation task encourages a sense of ownership for the students. Such ownership should provide intrinsic motivation as the students engage in sustained inquiry. Furthermore, every curriculum needs some sort of starting point. By encouraging the students to consider issues in planning a mission to Mars, they develop an appreciation for the complexities of the challenge.

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Initial Analyses of the Problem Generation Activity

Hickey et. al (1995) report initial attempts of analyzing problems posed during the first activity period of the Mars Mission curriculum. They analyzed 309 problems posed by 11 small groups of students and categorized them into groups to be used as anchors for instruction. Problems were considered "inside" or "outside" the general problem domain depending on the scientific challenge it presented. Problems categorized inside the domain concerned potential mission factors, while those considered outside were usually general questions about Mars, and were not posed in the specific context of a mission. The authors found that 178 (58%) of the problems generated were considered as inside the problem domain, which were satisfactory results, given that the activity's primary purpose was to motivate students sufficiently for sustained inquiry. Table 1 presents more detailed findings of the categories and frequencies of problems posed in their study.

Insert Table 1 about here

The Present Work

In our previous work, problem formulation was essentially treated as an independent variable. That is, we used the activity to structure classroom discussions, group formation, and to serve as an anchor for sustained inquiry. More recently, we have begun to think of problem formulation as a dependent variable-- being curious of potential differences between problems posed during the problem generation activity, and those that would be posed at the conclusion of the Mission to Mars curriculum. We believe that expertise gained through the sustained inquiry and activities of the curriculum should help the students to generate more appropriate, and more specific questions at the end of the unit. In the next two sections, we provide a brief theoretical account that motivates these hypotheses, and then discuss data recently collected in a Mission to Mars classroom that provides some support.

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Expertise and Context[1]

Modern educational theories often emphasize the role that context plays in learning. For example, Brown, Collins & Duguid's (1989) theory of situated cognition argues that "knowledge is situated, being in part a product of the activity, context, and culture in which it is developed and used" (p. 12, italics added). Emphasis on the role of context may also be seen in the work of Bransford, Franks, Vye, & Sherwood (1989). The authors argue that context helps the learner to notice the relevant features of a given event.

For the present purposes, some elements of context are the conditions which drive one's perception. Such conditions are often derived from prior knowledge. For example, consider figure 2. While examining the object, anyone familiar with it will construct a context that influences their perception of it. Such a context is derived from bits of experience, such as the fact that the object is a chair, is made of wood, is used for sitting, has a back, etc.

Insert Figure 2 about here

A true expert with chairs, perhaps one who constructs furniture as an occupation, would be able to see much more when examining the object. In this case, the person would probably notice that the chair presented in figure 2 would have a durability problem. A horizontal piece of wood is missing that substantially contributes to the chair's longevity. This piece prevents the chair from slowly developing a sideways wobble, without which the chair would eventually collapse. In other work, we have found that most people cannot provide the context to notice the absence of structure (see Czarnik & Schwartz, 1997). By contrasting figures 2 and 3, the reader may more easily notice the first chair's problem. In a sense, activating the appropriate or sufficient context depends, in part, upon sufficient expertise.

Insert Figure 3 about here

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This relationship of context to expertise has been also been advanced by others. Most notably, Bransford et. al. (1989) argue that wisdom (considered synonymous with expertise for our purposes), is something that cannot be told; it is the ability to spontaneously notice the distinctive features of a given situation. This conception of expertise as noticing has clear implications; as expertise in a domain improves, the distinctions to be made in noticing (or problem generation activity, as we shall argue) will become finer and finer. With respect to noticing, this hypothesis has been supported in a number of domains, including chick sexing (Biederman & Shiffrar, 1987), wine tasting (Solomon, 1997), tree identification (Medin, Lynch, Coley, & Atran, 1997), and geology (Bezzi, 1996).

Our account of expertise as noticing features by contextualizing an event may be used to explain many of the classic studies investigating the nature of expertise. Chase & Simon's (1973) study of expertise in chess is an excellent example. The authors found that experts can reproduce complex chess board configurations perfectly after only brief exposures, while novices are capable of reproducing only portions of the chess board configurations. Experts are capable of such accuracy because they have experienced thousands of different chess board configurations, and can encode complex configurations in a small number of "chunks," to use the author's terminology. By our account, the experiences of master chess players allow them to quickly construct an appropriate context when studying the chess board, a context constructed by noticing the important details relevant when one must adopt a response strategy to the situation depicted by the arrangement of the pieces. Novices didn't have this large base of prior experience to help them notice important features, and it was reflected in their poor recall performance. Indeed, for Chase & Simon's experts, chunking was noticing.

In another famous study, Chi, Feltovich & Glaser (1981) investigated categorization and representation of physics problems in experts and novices. They found that experts and novices categorized problems according to very different criteria. Experts typically represented problems in

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terms of the physical principle that is needed for solution (e.g. problems solved using Newton's second law). Novices typically represented problems in terms of surface or other unimportant features (e.g. problems that involve an inclined plane). The terminology used in Chase & Simon above applies here as well; while experts were able to bring to bear their vast knowledge of physics to understand the problems, noticing each problem's deep, structural characteristics, novices were forced to rely on surface features to understand the situations. Again, this noticing by experts resulted in a fundamentally different classification strategy when compared with novices.

Differences among experts and novices have long been an issue investigated by researchers embracing the direct perception hypothesis. Perhaps the most widely cited study in this class is the famous demonstration conducted by Gibson & Gibson (1955). In this classic experiment, subjects studied a series of scribbles presented on cards which varied along several dimensions. The task was for subjects to correctly identify certain target scribbles within the set of objects, most of which were slightly different than the target. Gibson & Gibson demonstrated that after several presentations of the set of cards, identification of the target scribble quickly became perfect. The subjects had developed a degree of expertise with the scribbles; they had learned to notice the features necessary to successfully complete the task.

Each of the three studies just described were conducted for very different reasons. Our point is not to make sweeping generalizations across these research programs, but rather to demonstrate the power of noticing as an explanatory construct. Regardless of potential underlying mechanisms, we agree, as do others (e.g. Bransford, et. al., 1989; Gibson & Gibson, 1955, E. Gibson, 1982, J. Gibson, 1977) that a major component of expertise within a domain is the ability to notice features which set a domain's entites apart from one another.

Problem Generation and Expertise

Brown & Walter (1990) claim that the first phase of problem posing involves "Accepting," or constructing a problem domain. However, what gets constructed can sometimes be problematic:

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> Many of us are blinded to alternative questions we might ask about any phenomenon because we impose a context on the situation, a context that frequently limits the direction of our thinking. We all do this to some extent because we are influenced by our own experiences... (p. 16).

We agree with this statement, and point out that the "context" Brown & Walter mention appears quite similar to the definition of context we presented earlier. It follows then that because increasing expertise allows richer constructions of context and thus the noticing of finer and more appropriate distinctions, problems generated should systematically vary with expertise.

Specifically, expertise within a domain should allow one to notice subtle features, just as the subjects in Gibson & Gibson's experiment were able to notice finer and finer distinctions among stimuli. This increased ability to differentiate should encourage more knowledgeable students to ask increasingly specific questions. Inversely, one with little experience in a domain would be expected to ask very general questions, many of which may lie outside of the content area's established boundaries. Highly specific questions posed by the novice would likely be inappropriate, or insignificant when examined with respect to the major issues that define the general problem domain. By analyzing students' questions generated in the Mission to Mars curriculum, we will provide some initial evidence that supports these predictions.

Method

Participants

A 6th grade class of 17 students using the Mission to Mars instructional unit participated in this study. The class was ethnically diverse, reflecting a typical inner-city classroom in the public schools of Nashville, TN. The teacher conducting the unit had a great deal of experience with the Mission to Mars curriculum, having taught the unit on several occasions. The class had numerous technological resources at its disposal, including multimedia capability and internet access.

Procedure

Immediately after viewing the Mars Mission Challenge video for the first time, students

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were told to generate and write down any questions related to completing a successful mission to Mars. Students worked on this task in 9 small groups, and the written questions were then collected for the subsequent problem generation activities (question sorting / group formation). Near the end of the Mission to Mars unit, students were again given the same task, and these questions were also collected. With the exception of the post-instruction problem generation task, the unit was conducted according to the summary provided in the previous section of this paper, and reported in more detail in Petrosino (1995).

Results

Pre and Post categorization of Problems

Problems generated by the students were categorized using the framework developed by Hickey et. al. (1995). As mentioned earlier, this involves a general "status" categorization, reflecting the problem's membership as "inside" or "outside" the general problem domain. Problems characterized as "inside" the problem domain are those which allude to potential mission factors. These problems were further categorized into one of 6 content categories: astronaut's health, life support issues, hardware issues, mission configuration issues, surface activity, and political problems. Overall, we found that 106 problems (44%) qualified as inside the problem domain. Table 2 presents frequencies of problems generated for each of the 6 content categories.

Insert Table 2 about here

The remaining problems generated at pretest were classified as those "outside" the problem domain. These problems were further classified into 5 content categories: conditions of Mars, colonization of Mars, questioning life on Mars, catastrophe concerns, and other / frivolous. We categorized 134 (56%) problems as outside the established domain. Frequencies of these problems are also reported in Table 2.

Percentage of problems categorized as inside and outside the established domain do not

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appear to be substantively different than those reported by Hickey et. al. (1995). Figure 4 presents plots of the percentages of classifications inside and outside of the problem domains for Hickey et. al., and initial and end of unit problem classifications for the present study. Although the percentages of content category classifications reported in table 2 sometimes differ substantially from those reported by Hickey et. al. (see table 1), the content categories seemed to fit the problems generated in this study (as measured by high reliability), so the these differences will not be discussed further.

Insert Figure 4 about here

Frequencies of various problems generated were very different on the task administered at the end of the unit. Overall, we classified 77% (91) of the problems as "inside" the problem domain, and 23% (28) as "outside." Further breakdowns are presented alongside initial generations in table 2, and differences between initial and post-instruction problem frequencies are plotted in figure 4.

Group membership changed substantially from initial generation activity to post-instruction generation, which unfortunately prohibited us from comparing initial and post-instruction generation activity within groups. This issue will be discussed further in the final section of the paper.

Specificity of Problems Generated

Although our rather crude classification of questions reveals differences in frequencies of problems generated that were inside or outside the inquiry domain from initial to post-instruction, this classification scheme was insensitive to much of what was interesting between the two attempts at generation. Looking at the actual problems generated, we found that the specificity of the problems generated from initial to post-instruction varied as well.

For example, within the "Mission Configuration" category, students asked questions such

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as "How will we get there?" Questions of this nature are so vague and unspecified that we had some difficulty in selecting the Mission Configuration category as appropriate in the first place. In contrast, the mission configuration questions were much more specific at post-instruction. Some students asked "What kind of route will they take," implying that more than one route is possible in travelling to Mars. Another group posed an even more specific version, naming the routes: "Which mission are we going to use... the opposition, sprint, or conjunction to go to the planet Mars?" Concerning the return mission, we found a group concerned with selecting an appropriate route: "Will we take the same route that we took going, coming back?"

Similar results were found in other categories as well. In the life support category, students had a tendency to initially pose questions involving general quantities of supplies needed to complete the mission. Several groups asked questions like "What kinds of supplies do we need," "How much oxygen do we need," or "Do we have enough water?" At post-instruction, questions were more specific. Instead of posing general quantities, they appeared to assume that some degree of efficiency must be established for successful completion of the mission. Questions posed more often concerned issues of recycling: "How do we recycle the oxygen and water?"

Although we have argued that the specificity of the problems differed from initial to post-instruction generation attempts, we are not claiming that some of the problems initially generated were not specific. To the contrary, we found problems that were highly specific on the initial attempts, but often this specificity was focused on otherwise trivial issues. For example, one group asked "How will the explorers be able to brush their teeth." Although this question poses a legitimate dilemma, in the context of planning a mission to Mars the problem appears quite insignificant. Overall, the majority of these highly specific, although trivial problems appeared on initial attempts at problem generation.

Discussion and Conclusions

To summarize, we found that initially students asked very general questions, which were often tangential to the established problem domain, presumably because they had little experience

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to be applied in planning a trip to Mars. Those questions posed initially that were well specified were often focused upon trivial issues, when faced with the overall challenge of planning such a complex mission. Relative to initial attempts, problems generated at post-instruction were more appropriate with respect to the planning task, and tended to deal with specific relevant issues. We believe that our conception of expertise as the ability to notice the important features of a situation provides a reasonable explanation for these results we have presented.

Although the present findings provide initial encouragement, we note that there are a couple of limitations. The nature of the data collected in this study prevented comparisons on an individual basis, so claims of the development of expertise are necessarily restricted to the classroom as a whole. We seek to overcome this limitation in future implementations of the curriculum, by structuring the generation tasks such that comparisons may be made between small groups or individuals from initial to post-instruction attempts. Comparing problem generation activity within the individual would permit several interesting analyses.

The results of this study are also limited in that we don't actually know if the types of problems generated at post-instruction are due to expertise, or are merely the students regurgitating details that they heard in class. Although we have argued that our results suggest expertise, in that students are able to identify more subtle distinctions and ask more appropriate questions, it could be the case that students learned nothing more than to ask the right questions, restating what they heard the teacher or another class member say. We believe this interpretation is unlikely, as other products generated by the class (e.g. portfolios) clearly demonstrate that some learning was taking place. Nonetheless, we believe this alternative explanation is plausible, and future efforts will seek to address this issue. Documentation of group activities along with pre and post instruction interviews of some students may help to provide evidence that students have developed a deeper, more specific understanding of the problem domain.

In conclusion, we have attempted to do several things in this paper. We have traced the evolution of the problem generation activity in the Mission to Mars environment from that of an

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independent variable (in structuring the classroom) to a dependent variable (in assessing performance). To motivate this evolutionary process, we have outlined a theoretical account of context and noticing, and their relationships to expertise. Finally, we have reported some initial empirical evidence that provides some support for our hypotheses, mentioning a couple of limitations.

As an independent variable, we have attempted to demonstrate the pedagogical value of problem generation activity. In addition to motivating students and developing a sense of ownership of issues in a domain, we believe it sensitizes students to the complexities of the tasks to be completed. When viewed as a dependent variable, problem generation activity offers exciting possiblities as an assessment tool. We have demonstrated an overall improvement of the problems generated after the Mission to Mars curriculum at the classroom level, and are conducting further research to better establish its validity in assessing individual students' understanding.

Footnote

[1]We must note that we consider "expertise" as a construct that is highly domain-specific, in contrast to domain-general conceptions that essentially treat expertise as some form of generalized intelligence. Several researchers (e.g. Getzels, 1964; Guilford, 1967; Getzels & Csikszentmihalyi, 1966; Arlin 1975/1976) have investigated the relationship of problem finding activity with domain-general forms of expertise (most notably creativity), and we refer the interested reader to Hickey (1993) for a review of the topic.

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Table 1

Categories (and number) of Problems Posed as Reported by Hickey, et. al. (1995)

Status	Content Category	Most Common Content Subcategory
Inside (178)	Health (53)	Illness (e.g., "What if someone gets sick?")
	Life Support (42)	Oxygen (e.g., "Where will we get oxygen?")
	Hardware (35)	Fuel (e.g., "How much fuel will we need?")
	Mission Config. (24)	Trip Length (e.g., "How long will it take?")
	Surface Activity (14)	General (e.g., "What will we do there?")
	Politics (10)	Cost (e.g., "How much will it cost to get there?")
Outside (131)	Mars Conditions (37)	Atmosphere (e.g., "Is there oxygen on Mars?")
	Colonization (25)	Facilities (e.g., "Are there aliens on Mars?")
	Life on Mars (14)	Aliens (e.g., "Are there aliens on Mars?")
	Catastrophes (30)	Equipment Failure (e.g., "What if we blow up?")
	Other & Frivolous (25)	(e.g., "Will I have to take my sister?")

Table 2

Categories of Problems Posed Initially and Post-Instruction.

		Generating Condition	
Status	Content Category	Initial	Post-Instruction
Inside	(Total)	106	91
	Health	12	4
	Life Support	39	19
	Hardware	16	28
	Mission Config.	27	30
	Surface Activity	9	5
	Politics	3	5
Outside	(Total)	134	28
	Mars Conditions	64	7
	Colonization	7	2
	Life on Mars	27	4
	Catastrophes	12	4
	Other & Frivolous	24	11

Figure 1. The Mission to Mars Instructional Sequence.

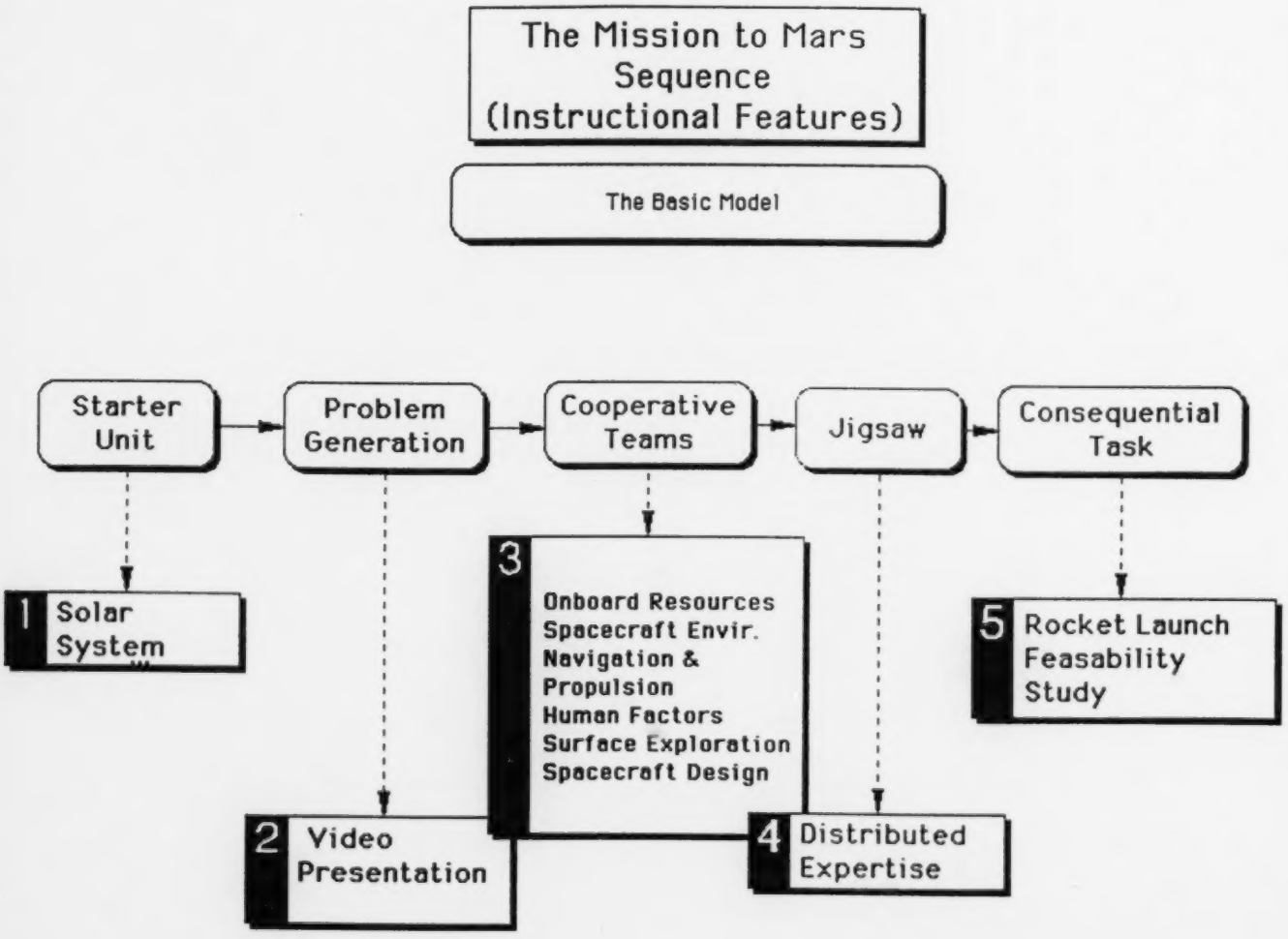

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Figure 2.

Figure 3.

Figure 4. Domain Classifications for Hickey et. al. and the Present Study